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SOME EFFECTS OF THE ATMOSPHERE AND MICROPHONE PLACEMENT ON AIRCRAFT FLYOVER NOISE MEASUREMENTS

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16. Abstract
The NASA Langley Research Center recently participated in a joint program with the FAA to study the effects of varying atmospheric conditions relative to certification-type noise measurements. These tests were made under various atmospheric conditions at two test sites, Fresno, California, and Yuma, Arizona, using the same test aircraft, noise, and weather measuring equipment, and operating personnel. Measurements were made to determine the effects of the atmosphere and of microphone placement on aircraft flyover noise. Presented in the paper are descriptions of the test setup and the type of measurements obtained for characterization of not only the acoustic signature of the test aircraft, but also specific atmospheric characteristics. Data are presented in the form of charts and tables which indicate that for a wide range of weather conditions, at both site locations, noise data were repeatable for similar aircraft operating conditions. The placement of microphones at ground level and at 1.2 m over both spaded sand and concrete illustrate the effects of ground reflections and surface impedance on the noise measurements.

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INTRODUCTION

In order to produce a comprehensive system for aircraft flyover noise prediction, and to better understand acoustic research conducted outdoors in the real atmosphere, one must firmly establish the effects of atmospheric temperature and humidity and the ground reflecting surface on the propagation of aircraft noise. References 1 through 18 are indicative of the concerted efforts by several researchers to provide a better understanding of these effects. NASA Langley has several research studies in this area relating to both the theoretical and experimental aspects of the propagation problem. These studies involve measurements in the laboratory and outdoors in the real atmosphere. The outdoor studies include experiments utilizing fixed acoustic sources atop tall towers (ref. 19) and aircraft flyovers.

Recently, a cooperative multiagency flyover noise study was conducted involving the NASA, FAA, NOAA, and NCAR. The purpose of this study was to evaluate the effects of varying atmospheric conditions on noise certification-type measurements. In this study, the opportunity

was taken to obtain aircraft flyover noise data under controlled operating conditions for noise propagation purposes. These tests were made under a wide variety of atmospheric conditions at test sites in Fresno, California, and Yuma, Arizona; using the same aircraft, weather and noise measuring equipment; and operating personnel. Approximately 270 separate flyovers of the test aircraft were made over a 21-day period. The study provided a large data base for analysis and evaluation of the effects of atmospheric conditions on outdoor sound propagation.

The purpose of this paper is to present a general description of the ranges of test conditions encountered and the methods and procedures utilized, as well as some of the initial results showing variations in the observed noise levels due to atmospheric and microphone location effects.

SYMBOLS AND ABBREVIATIONS

dB(A)	A-weighted SPL, dB
EPNL	Effective perceived noise level, EPNdB
F_n/δ	Single-engine thrust divided by the ratio of flight altitude pressure to sea-level reference pressure, N
M	Mean value
N	Total number of events (flyovers) in a given data set
OASPL	Overall (25 Hz to 12.5 kHz) SPL, dB
P	Measured acoustic pressure, N/m^2
P_o	Reference pressure, 2×10^{-5} N/m^2
PNLT	Tone corrected perceived noise level, PNdB
PNLTM	Maximum tone corrected perceived noise level, PNdB
SPL	Sound pressure level, 20 log (P/P_o), dB

TM Telemetry

σ Standard deviation

Subscripts

F Fresno, California

Y Yuma, Arizona

APPARATUS AND METHODS

The test program involved constant altitude flights over a fixed microphone array. The test aircraft, an FAA-owned DC-9-10, was flown at several power settings at altitudes of 610 m, 335 m, and 152 m. During the tests, weather parameters and the aircraft position and operating conditions were also obtained. Indicated schematically in figure 1 is the general test arrangement. Shown are several systems used to measure temperature, humidity, wind, and turbulence profiles. One system, an FAA-developed meteorological system installed in a small general aviation aircraft, measured temperature, dewpoint, and the wind-induced turbulence structure constant from the surface to an altitude of 900 m (see ref. 20). A second system, consisting of an NCAR-developed boundary-layer profiler suspended from a 4.9 m long kytoon, measured wet and dry bulb temperatures, barometric pressure, windspeed, and the temperature-induced turbulence structure constant over altitudes from 10 m to 300 m. Wind direction and speed, temperature, and humidity were also measured atop a 10 m tower. At Yuma, a double theodolite system, operated jointly by the U.S. Army Yuma Met Team and NOAA-Wallops Flight Center, provided windspeed and direction from the surface to an altitude of 900 m.

The NASA Langley Research Center provided a six-microphone array to measure the flyover noise. Three microphones were located at each of two measurement stations separated by about 610 m along the aircraft ground track. At each station, one microphone was placed over concrete and one microphone over spaded sand, each on a 1.2 m stand; the third microphone was flush-mounted on a 1 m by 1 m painted-plywood groundboard.

Optical techniques were utilized to determine the altitude, speed, and time of the airplane over each measurement station. The aircraft altitude was determined from photographs made by cameras located at each station. As the aircraft passed overhead the camera shutter was manually released and, simultaneously, a signal was recorded on the acoustic data tape. By knowing the distance between the camera and the time between shutter release signals on the tape, the groundspeed of the aircraft was computed. The shutter release signal also provided an indication of the overhead passage time of the test airplane.

ATMOSPHERIC DATA

Examples of the type of temperature, humidity, and windspeed profiles obtained at both test sites are presented in figure 2. Although inversion and noninversion conditions were obtained at both sites, a larger percentage of strong inversions, higher temperatures, and lower humidities was found at Fresno. Surface based inversion strengths ranged from isothermal to 3.89°C per 100 m. As implied in figure 2, the winds in Fresno were calm to test altitude in most cases. In Yuma, however, the windspeeds aloft were as high as 15 m/sec. The ranges of temperature and humidity encounter during these tests are indicated

in figure 3. These data are for an arbitrarily chosen altitude of 30 m. The Fresno data are represented by the circles and the Yuma date by triangles. It can be seen that a much larger temperature and humidity range was measured in Fresno (from approximately 10 percent relative humidity at 40°C to approximately 98 percent relative humidity at 8°C) than in Yuma (from approximately 40 percent relative humidity at 25°C to 70 percent relative humidity and 15°C).

ACOUSTIC DATA

The outputs of all six microphones in the acoustic measurement array were recorded on an FM tape recorder which had an essentially flat response from 20 Hz to 10 kHz. The output of one of the microphones (1.2 m over concrete) was analyzed "online." From this arrangement, "real time" one-third octave band spectra were computed (using a moving 1.5 sec average) for each one-half second interval during the flyover. These spectra were then used to compute OASPL, dB(A), and PNLT time histories.

Figure 4 shows an example OASPL time history and the one-third octave band spectrum obtained at the maximum OASPL for a 152 m altitude flyover. The time history has a single peak and the spectrum has its maximum levels in the midfrequency range. The noise data presented in this paper are taken from flights resulting in time histories and spectra of this type.

The data are corrected only for measurement system response. It should be noted, however, that the variation in aircraft altitude which has not

been accounted for, could result in about a 0.3 dB to 0.5 dB correction for the altitude range covered in the tests.

Maximum A-Weighted SPL's

Figures 5a and 5b present histograms of the maximum A-weighted sound pressure levels from all the flights (29 at Fresno and 26 at Yuma) at an altitude of 610 m and a thrust of $F_n/\delta = 25{,}690$ N. On the ordinate is plotted the percent of the total number of flyovers at each site. The abscissa is the level of the maximum dB(A) values obtained at each site. Shown for each histogram, are the location of the mean value and the magnitude of the standard deviation. (The mean values are located to the nearest 0.1 dB. Thus, they may not be centered within the histogram bars.) It can be noted from figures 5a and 5b that the mean dB(A) level is higher for the Yuma data than for the Fresno data and that the standard deviation is higher for the Fresno data then for the Yuma data. The higher mean level in the Yuma data seems to be associated with higher humidities at that site. The larger standard deviation of the Fresno data seems to be associated with the wide range of humidities encountered at that site (fig. 3).

Although figure 5 is for a flight altitude of 610 m, it is representative of the results obtained for altitudes of 335 m and 152 m. The above trends in the mean and standard deviation were also found to apply to the OASPL's and one-third octave band levels.

One-Third Octave Band SPL's

The opportunity was also taken to examine the variation of the mean and standard deviation as a function of frequency and propagation distance.

The histograms in figures 6 and 7 illustrate that dependence. Figure 6a is a histogram of the 3,150 Hz one-third octave band SPL's taken from the maximum OASPL spectrum from 26 level flyovers at one of the test sites at 610 m. Similar data for the 1,000 Hz one-third octave band from 25 flyovers at the same site are shown in figure 6b. Two observations can be made from figure 6: First, the mean level is higher for the 1,000 Hz data than for the 3,150 Hz data. Second, the standard deviation is larger for the 3,150 Hz data than for the 1,000 Hz data. The higher mean level at 1,000 Hz would be expected based on the source spectrum and sound absorption over a 610 m propagation path. Also, as expected, the larger standard deviation at 3,150 Hz may be attributed to the larger sensitivity of the higher frequency to variations in atmospheric conditions.

Figure 7 illustrates the dependence of the distribution of the noise measurements on propagation distance. Figure 7a again, shows a historgram of the 3,150 Hz one-third octave band SPL's for 26 level flyovers at one of the test sites at 610 m. Similar data from 35 flyovers at 152 m is presented as figure 7b. Comparison of figures 7a and 7b shows a much larger standard deviation for the 610 m data than for the 152 m data (4.2 dB versus 2.6 dB, respectively). The differences between the standard deviations of the data in figure 7 are probably caused by a complex interaction of temperature, humidity, refraction, and scattering effects over the propagation distances.

It should be recalled that all of the discussion thus far relates to "as measured" noise data. As such, the effects of the atmosphere

have been accepted. However, data from this test program have been used, in conjunction with the procedures of references 21 and 22 and a layered atmospheric analysis, to correct the EPNL's to within ± 0.5 dB for the 355 m altitude flyover data (see ref. 23).

Effects of Microphone Placement

To show the effect of microphone placement on the noise measurements, the one-third octave band spectra measured at the time of PNLTM at the three placements (1.2 m over concrete, 1.2 m over spaded sand, and flush-mounted on a groundboard) have been plotted in figure 8. The higher groundboard levels are to be expected due to pressure doubling at the surface. The shapes of the three curves are nearly identical above 500 Hz; below 500 Hz the groundboard smooths out the pseudotones associated with ground reflections. The data in figure 8 show only small differences between the spectra for the microphones over concrete and spaded sand, but there is a consistent trend toward slightly lower levels over sand.

CONCLUDING REMARKS

This report has presented a general description of a test program having the objective of gaining more insight into the effects of a real atmosphere on flyover noise data. The trends observed in the "as measured" A-weighted and one-third octave band flyover noise data recorded in Fresno, California, and Yuma, Arizona, have been described. Although a large amount of analyses remain, a number of observations can be made based on these data: The flyover noise

data recorded in these tests were made under a wide range of temperature and humidity; the winds, however, were mostly calm. Preliminary analyses have produced results which seem to be consistent with the existing observations, that is, the variations in measured flyover noise are primarily associated with the variation in atmospheric conditions at the test sites. The microphones placed at ground level show a reduction in tone and cancellation effects but an increase in spectrum levels.

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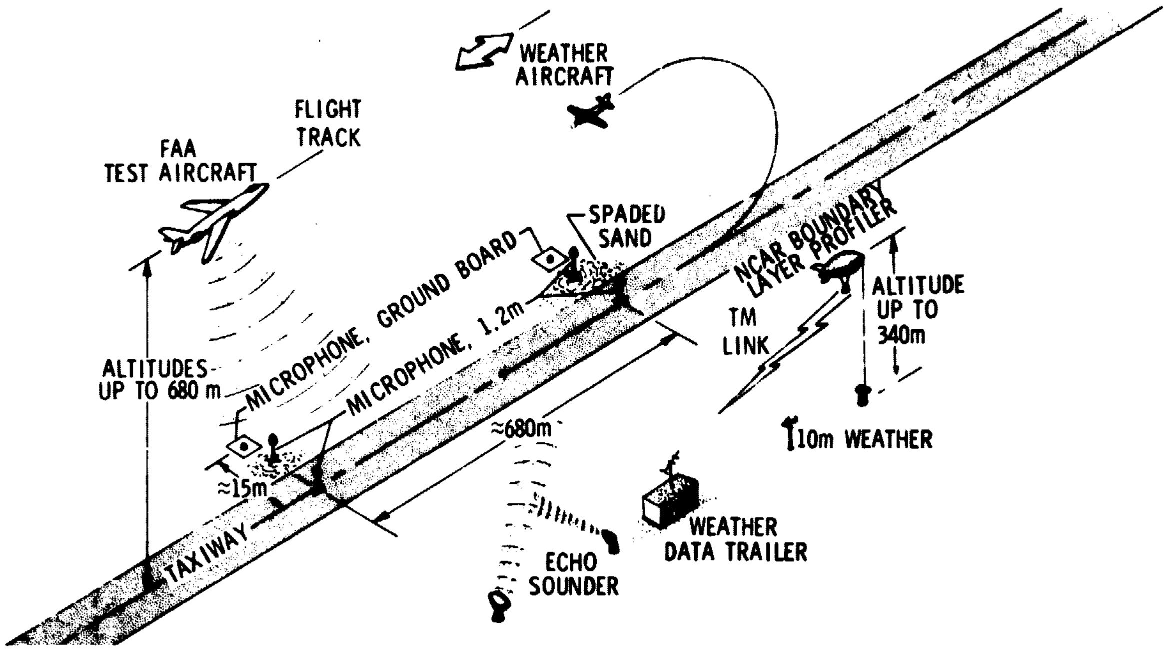


Figure 1.- Schematic of test range showing test aircraft and measurement systems.

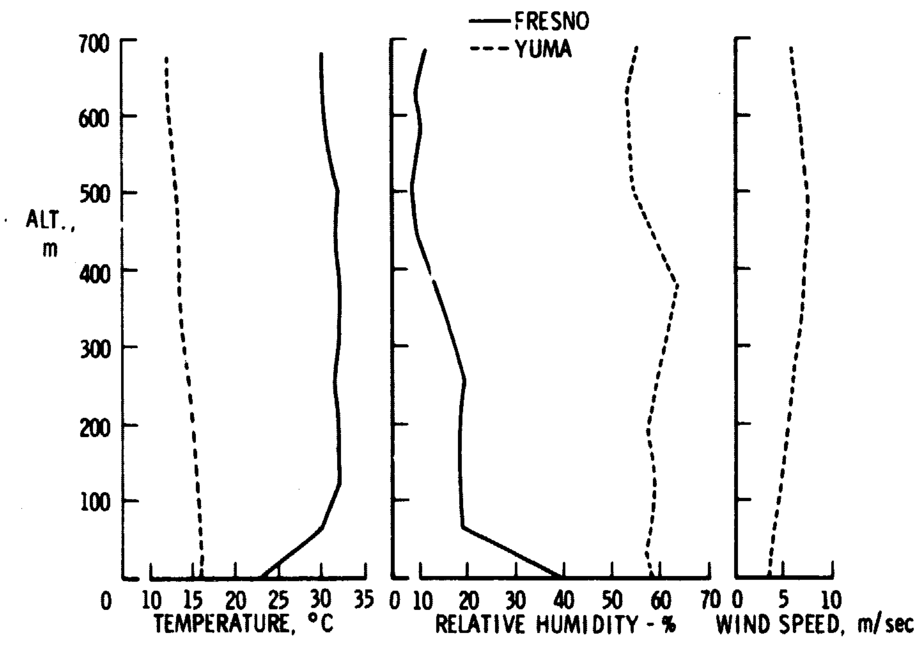


Figure 2.- Examples of temperature, humidity, and windspeed profiles measured at both test sites.

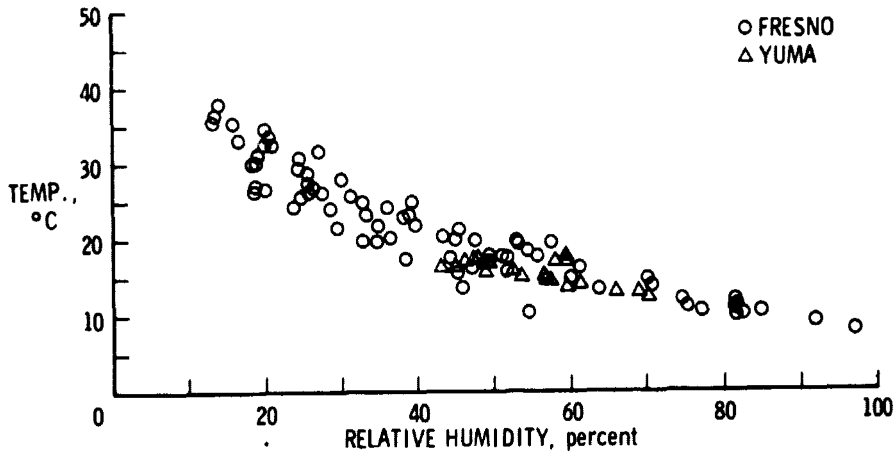


Figure 3.- Ranges of temperature and humidity measured at both test sites at an arbitrarily chosen altitude of 30 m.

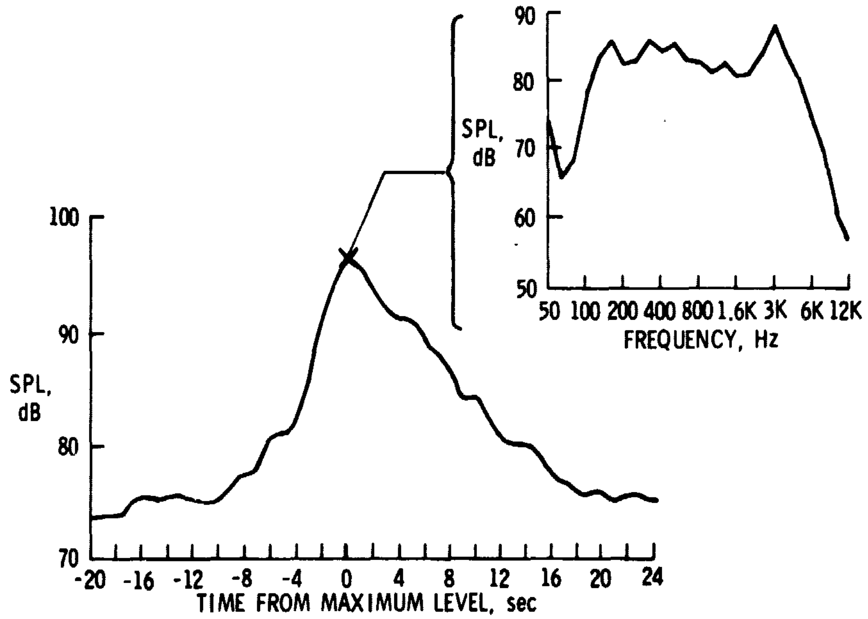
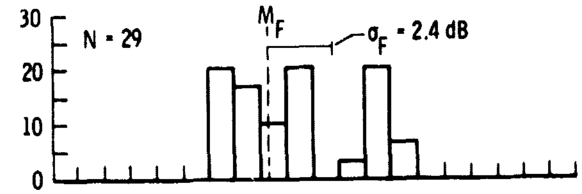
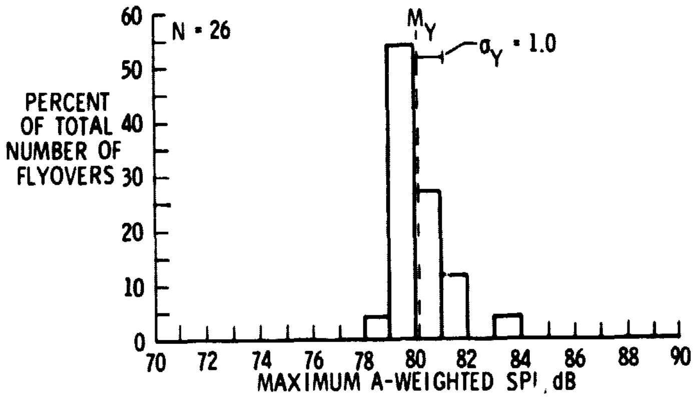


Figure 4.- Example OASPL time history and one-third octave band spectrum.



(a) Fresno



(b) Yuma

Figure 5.- Histograms of maximum A-weighted SPL's from all flights, at an altitude of 610 m and an F_n/δ = 25,690 N, at (a) Fresno and (b) Yuma.

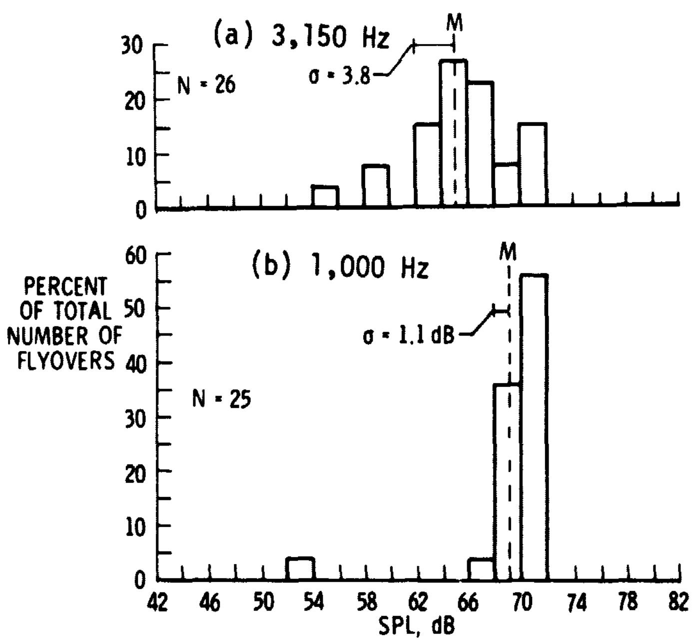


Figure 6.- Histograms of the (a) 3,150 Hz and (b) 1,000 Hz one-third octave band SPL's taken from the maximum OASPL spectra for 610 m altitude flyovers.

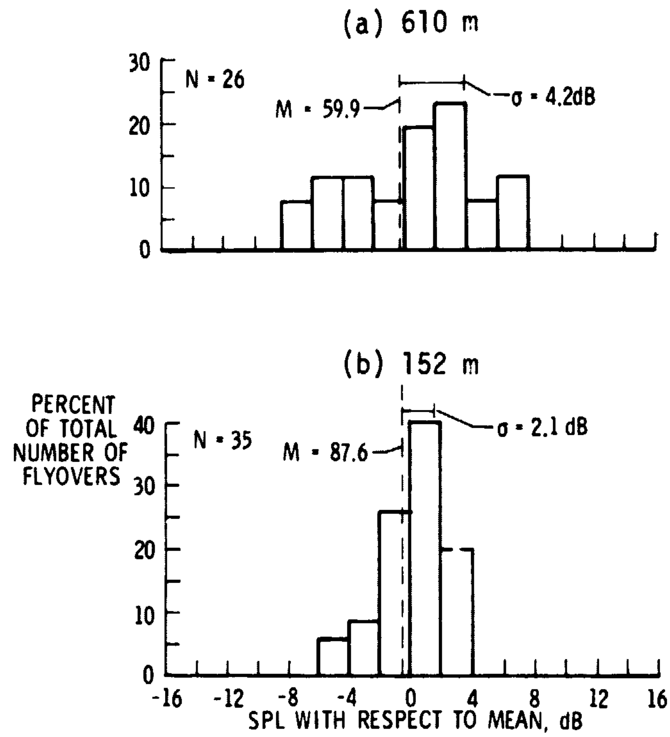


Figure 7.- Histograms of the 3,150 Hz one-third octave band SPL's taken from the maximum OASPL spectra for aircraft flyovers at (a) 610 m and (b) 152 m.

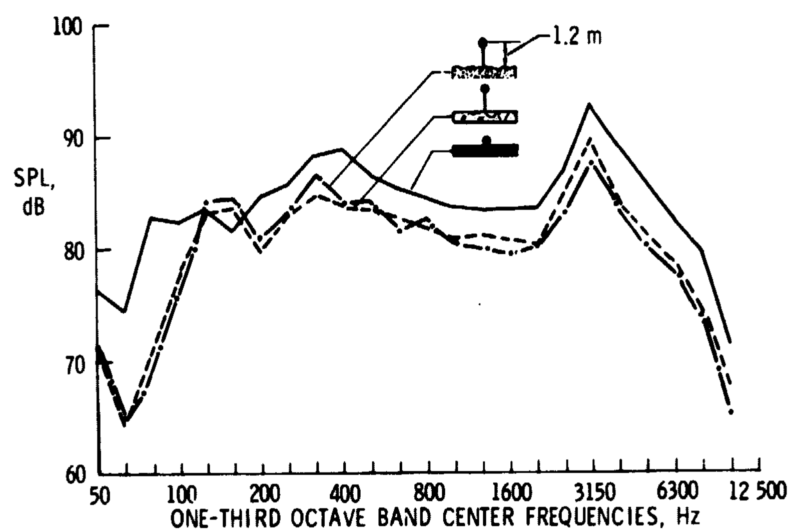


Figure 8.- One-third octave band spectra measured at the time of PNLTM with microphones 1.2 m over concrete, 1.2 m over concrete, and flush mounted on a plywood groundboard.